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A Review of Ash in Conventional and Advanced Coal-Based Power Systems

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A REVIEW OF ASH IN CONVENTIONAL AND ADVANCED COAL-BASED POWER SYSTEMS

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ABSTRACT

Process conditions are briefly described for conventional and advanced power systems. The advanced systems include both combustion and gasification processes. We discuss problems in coal-based power generation systems, including deposition, agglomeration and sintering of bed materials, and ash attack are discussed. We also discuss methods of mitigating ash problems and anticipated changes anticipated in ash use by converting from conventional to advanced systems.

INTRODUCTION

Coal-fueled power generation is closely tied to the complications of coal-ash generation. The inorganic components contained in coal are converted to ash during combustion or gasification. The resulting ash can cause significant problems that include slag flow irregularities, ash deposition, bed agglomeration, corrosion and erosion of system parts, and bridging and blinding of high-temperature filters. The properties of the ash in coal conversion systems are tied directly to system conditions, coal properties, inorganic transformations involved in the coal conversion process, and the fluid dynamics of the process. If the ash properties and the dynamics of a system are known, techniques to mitigate problems associated with ash generation can be developed.

PROCESS SYSTEMS

Depending on the process conditions, the inorganic constituents in coal can go through significantly different physical and chemical transformations. However, understanding the ash behavior and fluid dynamics of one process can enable predictions to be made concerning ash behavior under similar conditions.

Conventional Power Systems

Conventional coal-fired power generation systems generally fall into two types according to whether their furnaces are designed for removal of ash in dry or molten form. Dry ash furnaces are frequently referred to as "dry bottom" furnaces, and molten ash furnaces are normally called "slag tap" or "wet bottom" furnaces. Currently, dry ash furnaces are much more common. Figure 1 shows the general configuration of a conventional coal-fired utility boiler. The coal is burned with 20 to 25 percent excess air. Roughly 10 percent of the ash is removed from the bottom of the boiler, and the remainder is collected as fly ash at the end of the system. The temperature range of the primary and secondary superheaters is generally between 1,800 ° and 2,400 °F (980 ° and 1300 °C). The economizer temperature is usually between 1,000 ° and 1,200 °F (540 ° and 650 C).

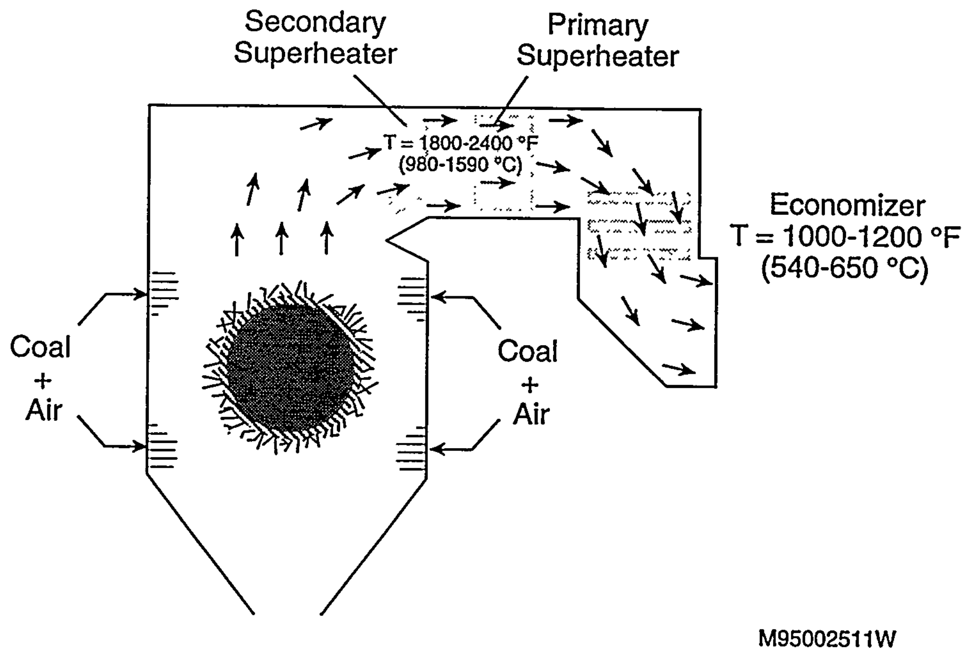


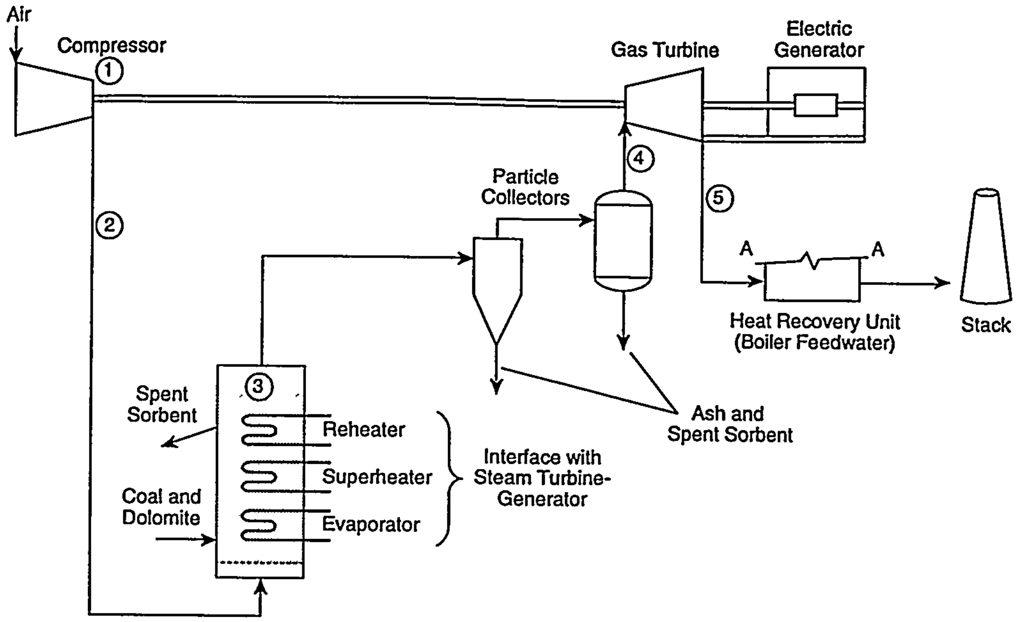
Fig. 1. Conventional Pulverized Coal-Fired Utility Boiler

ADVANCED POWER SYSTEMS

The DOE is involved in research, development, and demonstration (RD&D) of advanced coal conversion power systems, including fluid-bed combustion, integrated gasification combined cycle, and externally fired systems. The motivation for these advanced conversion systems is increased efficiency and a decrease in capital costs.

Advanced Combustion

In fluidized-bed-combustion (FBC) processes, solids are fluidized and fuel particles are combusted to sustain a given process temperature. The solids in FBCs are generally fuel, ash, and a sorbent which is used to control pollutants. FBC systems operating at atmospheric pressure are classified as atmospheric fluidized-bed combustors (AFBCs). AFBCs usually have low fluidizing velocities that result in a bubbling bed. Circulating fluidized-bed combustors (CFBCs) operate at gas velocities approximately seven to eight times higher. This higher velocity entrains a portion of the bed which is continuously carried out with the gas and is recirculated back to the combustion chamber. Pressurized fluidized-bed combustion (PFBC) systems are similar to AFBCs but operate under high pressure. A brief schematic of a PFBC boiler plant is shown in Figure 2. PFBC systems can have smaller combustors since they use compressed air which results in higher intensity combustion. The other principle advantage is an increased conversion efficiency to electricity.



Station	1	2	3	4	5
Pressure, kPa (psia)	101.4 (14.7)	1013.6 (147)	965.3 (140)	930.8 (135)	105.5 (15.3)
Temperature, °K (°F)	288 (59)	597 (614)	1255 (1800)	1233 (1760)	776 (937)
Excess Air, %	--	--	21	21	30

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Fig. 2. Pressurized Fluidized-Bed Boiler Plant

As environmental concerns around the country increase, the production of nitrogen oxides from coal combustion is becoming an important issue. Significant reduction in nitrogen oxide production can be achieved by staged combustion which is a two-step combustion process. Partial combustion is conducted under fuel-rich conditions in the first stage followed by lean-stage combustion in the second stage.

Gasification

Coal gasification systems convert coal to a combustible gas, fine particulate, and ash or slag. The ash can be dry, agglomerated, or a slag. Fixed-bed gasifiers, such as the Lurgi, operate by passing air or oxygen and steam up through a bed of coal. Coal is added to the top of the bed and dry ash is removed through a grate at the bottom. Other fixed-bed gasifiers, which operate at higher temperatures such as the British Gas Lurgi (BGL), remove slag through a tap in the bottom. Fluidized-bed gasifiers, which include the U.S. Kellogg Rust Westinghouse (KRW), Institute of Gas Technology (IGT) processes, and the German Winkler process, operate in a gasification mode using steam and air or oxygen in a manner that resembles PFBC. These gasifiers produce dry ash or a fused agglomerated ash, depending on the operating temperature and the fusion temperature of the ash. Entrained-flow gasifiers, such as the Dow, Texaco, and Shell designs, operate at very high temperatures and produce a vitreous slag. Integrated gasification combined-cycle (IGCC) systems directly link various types of gasifiers with a gas turbine-steam turbine cycle to achieve high efficiency. Generic fixed-bed, fluidized-bed, and entrained-flow gasification reactors and bed temperature profiles are shown in Figure 3.

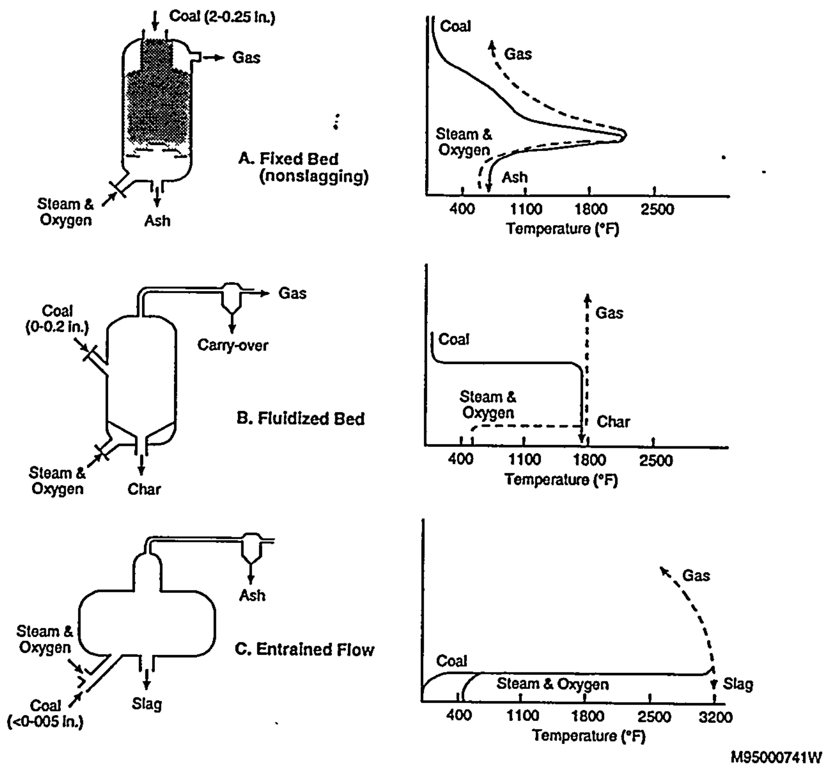

Fig. 3. Generic Coal Gasification Reactors

High-Temperature Filters

In order to gain efficiency, advanced power systems often use high-temperature filters to remove particulates. Properly operating high-temperature filters allow virtually no particulate matter to pass which enables the use of high-efficiency turbines. However, high-temperature filters have, on occasion, formed ash bridges in the filter system with catastrophic results. This can be mitigated by including large-size particulates in the effluent that reaches the filter. Other problems include binder depletion of the filter matrix and chemical attack of the filters by the high-temperature reaction gases. Alternatives to high-temperature filters include tandem high-efficiency cyclones followed by a lower-efficiency ruggedized turbine, or cooling the combustion products and then use a moderate-temperature filter.

PROBLEMS ASSOCIATED WITH ASH

Deposits in Utility Boilers

The characteristics of a deposit depend on the chemical and physical characteristics of the intermediate ash species, the geometry of the system, gas temperature, gas composition, and the gas velocity. Deposits that form in the radiant section of a pulverized coal boiler are called slag deposits. Slag deposits are exposed to radiation from the flame and are usually associated with a high level of liquid phase components. Silicate liquid phases are typically the most prevalent, although the deposit may also contain moderate to high levels of reduced iron phases. These initial slag deposit layers may consist of very fine particulate, which can be highly reflective. Fouling deposits form in the convective passes of utility boilers and often do not contain the high levels of liquid phases that are usually associated with slagging deposits. Fouling deposits contain low levels of liquid phases (e.g., a combination of silicates and sulfates) that bind the particles together. The formation of these deposits on heat-transfer surfaces can significantly reduce the efficiency and operation of the system.

Ash in Advanced Power Systems

Although FBCs typically operate at low temperatures (1,450 ° to 1,700 °F) (790 ° to 930 °C), evidence from pilot, industrial, and utility boilers indicates that certain ash components can cause ash-related problems. These problems include agglomeration and sintering of the bed material and ash deposition on the heat exchanger tube surfaces.

Bed material agglomeration is caused by small bed particles sticking together to form larger masses. Coal ash can react with the bed material to form a substance that acts like a glue in agglomeration. These ash-related interactions occur under normal FBC operating conditions and include the formation of low-temperature eutectics between sodium, potassium, and calcium components. Agglomeration can also result from localized hot spots of bed material where temperatures can sometimes exceed 1,700 °F (930 °C). In general, the ash deposition in advanced combustion systems is similar to that in conventional utility boilers, given a similar ash at corresponding temperatures.

MITIGATION

Many mitigation techniques can be used to ease ash problems, but they generally have associated costs. Coal switching or coal cleaning will change the ash chemistry and thus the slagging or deposition characteristics. Other methods involve lowering the temperature, which will lead to less efficient systems, such as dropping the boiler load, or reducing the temperature by increasing the excess air or by flue gas recirculation. Increased frequency of soot blowing can often remove problem ash but will increase capital investment and operating costs. The use of chemical additives is an evolving technology that produces similar effects to coal switching or coal cleaning. There will be a continuous cost for the additive and a small capital cost for feed equipment.

Ash Use

Commercialization of advanced coal technologies may have major impacts on the management of by-products. Many of the advanced technologies capture sulfur using dry sorbents, which is not as efficient a method as wet-scrubbing flue gas cleanup (FGC). Consequently, the volume of the by-product stream increases because of increased sorbent use. The increase in unreacted sorbent, typically calcium oxide, results in high alkalinity for many of these by-products. The high alkalinity has regulatory and waste handling implications but may impart utilization benefits by promoting pozzolanic chemical reactions with other coal by-products.

Combustion of coal under sub-stoichiometric conditions (i.e., coal gasification) generates reduced species, such as sulfides, in some by-products. The by-product can be classified as hazardous under Resource Conservation and Recovery Act (RCRA) regulation if the release of sulfides is above a specified level. Reduced forms of sulfur can be oxidized and removed as calcium sulfate with a calcium-based sorbent. High levels of sulfides are found in the solid by-products of in situ gasification before oxidative roasting. High levels of sulfides can also occur in slagging combustors with sorbent addition.

Low nitrogen-oxide burners can increase the amount of unburned carbon in the fly ash. The high carbon content can make fly ash unsuitable for cement replacement in concrete which is its largest, most valuable market.

Sources used in the preparation of this paper and other general reading on the topic are listed below.

SUGGESTED READING

1. S.A. Benson, ed., 1992. *Inorganic Transformations and Ash Deposition During Combustion.* American Society of Mechanical Engineers, for the Engineering Foundation: New York.

2. S.A. Benson, J.P. Hurley, C.J. Zygarlicke, E.N. Steadman, and T.A. Erickson, 1992. Predicting Ash Behavior in Utility Boilers: Assessment of Current Status. In *Proceedings of the 3rd International Conference on the Effects of Coal Quality on Power Plants*; LaJolla, CA, August 25-27.

3. S.A. Benson, J.P. Hurley, C.J. Zygarlicke, E.N. Steadman, and T.A. Erickson, 1993. Predicting Ash Behavior in Utility Boilers. *Energy & Fuels* 7(6):746-754.

4. S.A. Benson, M.L. Jones, and J.N. Harb, 1993. Ash Formation and Deposition. In *Fundamentals of Coal Combustion for Clean and Efficient Use.* D.L. Smoot, ed., Coal Science and Technology 20 Series, Elsevier: Amsterdam, Chapter 4, pp. 299-373.

5. R.W. Bryers and K.S. Vorres, eds. 1988. *Proceedings of the Engineering Foundation Conference on Mineral Matter and Ash Deposition from Coal.* Feb. 22-26, Santa Barbara, CA, Unit Engineering Trustees Inc.

6. G. Couch, 1994. Understanding Slagging and Fouling During pf Combustion, IEA Coal Research Report. The Impact of Ash Deposition on Coal Fired Plants. *Proceedings of the Engineering Foundation Conference.* June 20-25, 1993, Solihull, England; J. Williamson and F. Wigley, eds, Taylor J. Francis: London.

7. M.L. Jones, D.P. Kalmanovitch, E.N. Steadman, C.J. Zygarlicke, and S.A. Benson, 1992. Application of SEM Techniques to the Characterization of Coal and Coal Ash Products. In *Advances in Coal Spectroscopy*, H.L.C. Meuzelar, ed., Plenum Press: New York.

8. E. Raask, 1985. Mineral Impurities in Coal Combustion, *Hemisphere.* Washington.

9. E. Raask, 1988. Erosion Wear in Coal Utility Boilers, *Hemisphere.* Washington.

10. D.E. Rosner, 1986. *Transport Processes in Chemically Reacting Flow Systems.* Butterworth Publishers.

11. A.F. Sarofim, J.B. Howard, and A.S. Padia, 1977. The Physical Transformation of the Mineral Matter in Pulverized Coal Under Simulated Combustion Conditions. *Combustion Science Technology* 16:187-204.

12. N.M. Skorupska and A.M. Carpenter, 1993. *Computer-Controlled Scanning Electron Microscopy of Minerals in Coal.* IEA Coal Research Report.